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Geobags for Riverbank Protection

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INTRODUCTION

The large rivers in the deltaic country of Bangladesh are up to 30 m deep in places, and scour even deeper. Strong river currents erode the fine sand from the toe of the riverbank, steepening its slope. The upper bank then fails as a wedge slide or in some cases as a flow slide. The river removes the slide material from the toe of the slope and the erosion process repeats. In the Jamuna River, banks have receded locally by more than 1 km in a single year. In addition, there are numerous small rivers with the same sandy banks. In this nation, bank erosion is pandemic.

The traditional bank erosion protection is too expensive for almost all applications in the large rivers. Costs ranged from USD 29 M to 6 M per kilometer of bank protected with revetments [1]. There are shortages of local aggregate for concrete; no suitable rock for riprap; no heavy marine equipment for construction; troublesome river currents; and great depths to protect.

Instead, the resources of the country are sand, labor, and experience with simple floating equipment. Geobags – geotextile bags filled with fine river sand – serve to reduce costs to feasible level for protection. About half the cost for the slope protected with geobags is the purchase of the geotextile material. Initially, the geotextile fabric was imported in large rolls. Now, it is also produced locally.

Here, the ongoing efforts to protect the Padna Irrigation and Rural Development Project (PIRDP) with geobags adjacent to the Jamuna River are described. Another project at the confluence of the Padma and Upper Meghna Rivers was protected in the same way at the same time, but is not reported here.

THE SITE AT THE PIRDP

The PIRDP is a Flood Control, Drainage, and Irrigation (FCDI) Project protected from Brahmaputra/Jamuna River flooding by earthen embankments, and is drained and irrigated by sluice gates and aided by pumping. There are 35,000 ha and 250,000 people inside the embankments. The Project was put into operation in the late 1980's and became threatened by riverbank erosion in the late 1990's.

The site is approximately 25 km upstream from the Jamuna-Ganges confluence. The rates of bankline erosion are in the order of 100 m per year and vary along a 14-km reach starting upstream where the small Hurashagar River joins the Jamuna from the west (Fig. 1). A section of embankment was retired from the immediate riverbank in 1997/98 just before it would have disappeared into the river. Since erosion was continuing, efforts changed from moving the embankment to stopping the erosion. Moving the embankment again was not socially or politically acceptable.

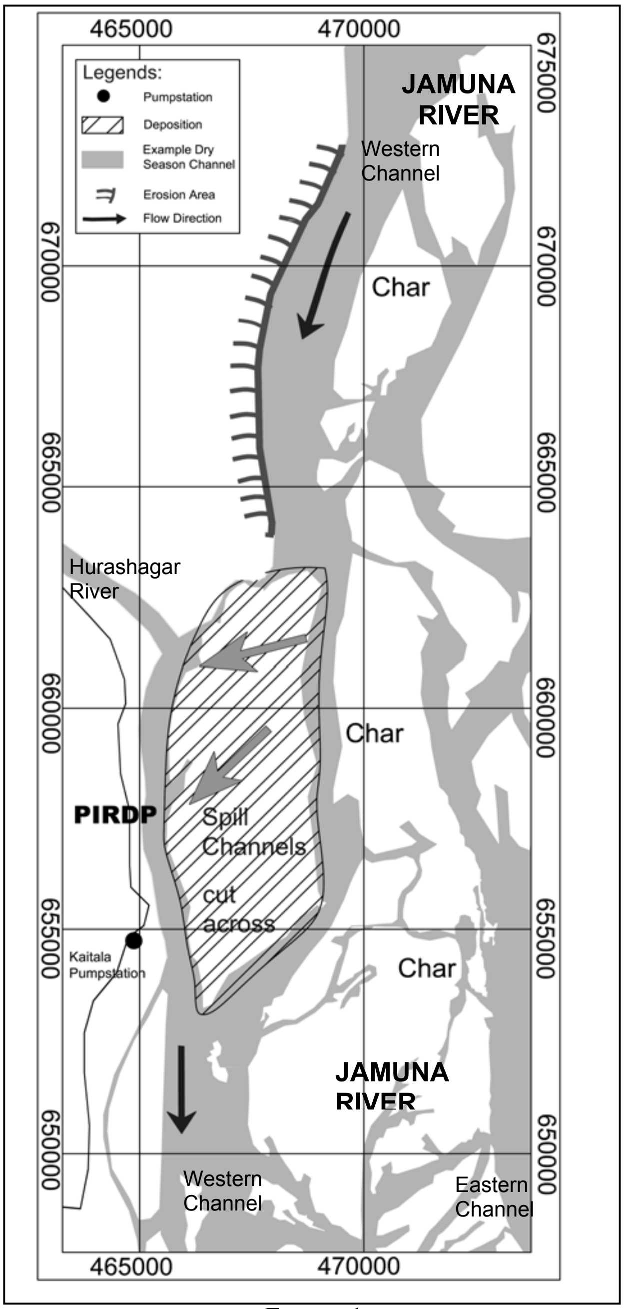

FIGURE 1

RIVER SITUATION ALONGSIDE THE PIRDP. NOTE THAT PROTECTIVE WORKS HAS BEEN BUILT FROM KAITALA TO THE HURASHAGAR RIVER.

By the time a feasibility study had been completed a crises had been reached. An emergency placing of geobags was begun to save the Project and a disaster plan was conceived in case the bank protection was not adequate.

River Morphology

The Jamuna River is braided with generally two major channels on the east and west sides, islands in the middle and smaller channels cross-connecting the east and west sides. The Hurashagar River adds a complexity to the west bank hydrodynamics, creating a small but influential confluence with its mammoth neighbor. The bankfull depth in the area of deep scour is approximately 30 m at times and is marked on the surface during low flow by an upwelling of brown water in the clearer current.

Flow along the eroding bank is essential north-south, and parallel to the bankline during the flood season but angles towards the bank during the dry season. The lowest scoured bed level can be during low-flow. The morphology is now well understood. The bankline movement at the Project is the result of bankline erosion upstream of the Hurashagar delivering an extra large load of sediment to the sandbars next to the Project (Fig. 1).

The Jamuna River carries as much as 85,000 m^3/s during large floods but that discharge is spread on average across a 12.5-km wide expanse of major and minor channels and island floodplain. It is the water that travels immediately adjacent to the Project bankline at speeds up to 3 m/s that define the protection works underwater. Eroding bank slopes are on average 1 vertical to 2 horizontal (1V:2H). At the surface strong winds cause 1-m high waves that erode the exposed bankline so protection is needed for that as well.

Development of Geobag Protection

The riverbank protection concept developed in phases:

1. Initial experimentation during the mid-1990
2. Suggested for emergency protection alongside the PIRDP in 2000
3. -Feasibility level designs in 2002
4. Modified designs implemented since 2004.

a. Initial Experimentaiton during the mid 1990

Several projects used geobags as alternatives for mostly temporary works as emergency protection or as falling aprons. Little systematic reporting on these developments exist even though in some places work has withstood all loads since 10 years now.

b. Emergency Proetction in 2000

The DHV Consultants [1] proposed to fill geotextile bags (geobags) with local sand and place them on the eroding bank as a feasible emergency measure. The case for this solution is that sand and labor are in plentiful supply and inexpensive. The bagsize was 250 kg.

Initial placement of geobags in 2001 was done along the riverbank as an emergency measure – it was a case of "do it now or lose the project." At the same time, a disaster plan was prepared in case the river should breach the flood-control embankment. To the extent that the Project is still intact, it can be claimed that protection with geobags has been a success.

c. Feasibility Level Design in 2002

Halcrow and Associates [2, 3, 4] conducted the feasibility study of geobag protection and recommended that bank-slope revetment of geobags was viable. However, there were questions about the technical feasibility. Certain basic assumptions about geobags could not be proven either theoretically or by experience, in-country or elsewhere. The proposed geobags design was essentially experimental, based on knowledge of "trench-filled" revetment behavior in the USA (Fig. 2). Plans were made to accommodate changes for the geobag revetment if they appeared necessary or advisable. This need for change became known as the "adaptive approach." Adaptation would be necessary because the behavior of the bags on the eroding bank was not certain and the river is prone to change in ways that are not entirely predictable, even in the short term.

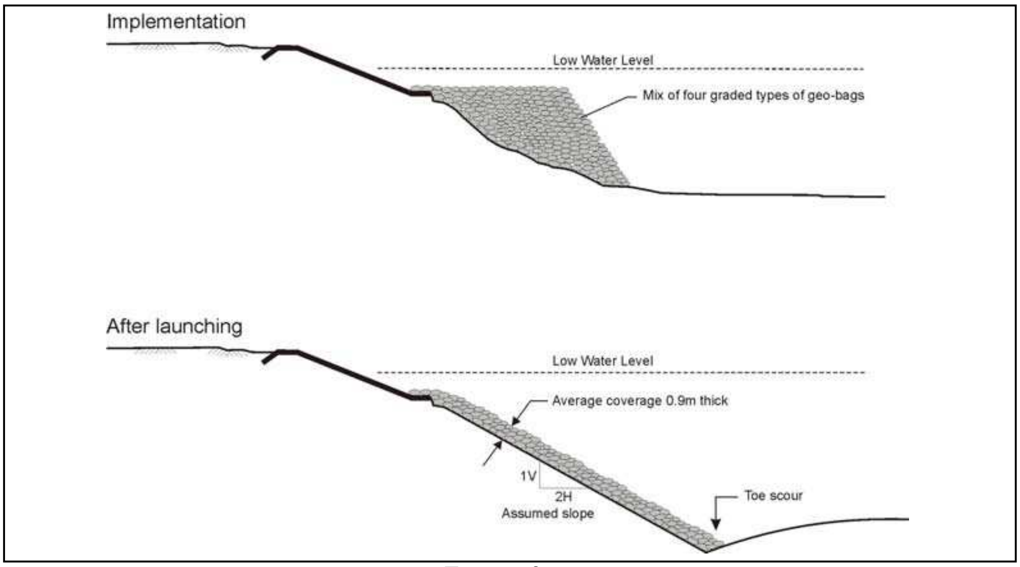

FIGURE 2
FEASIBILITY DESIGN CONCEPT: A HEAP OF BAGS DUMPED FROM THE BANKLINE LAUNCHES DOWN THE SLOPE PROVIDING AN AVERAGE 0.9 M THICK PROTECTIVE LAYER ON A SLOPE OF 1V:2H

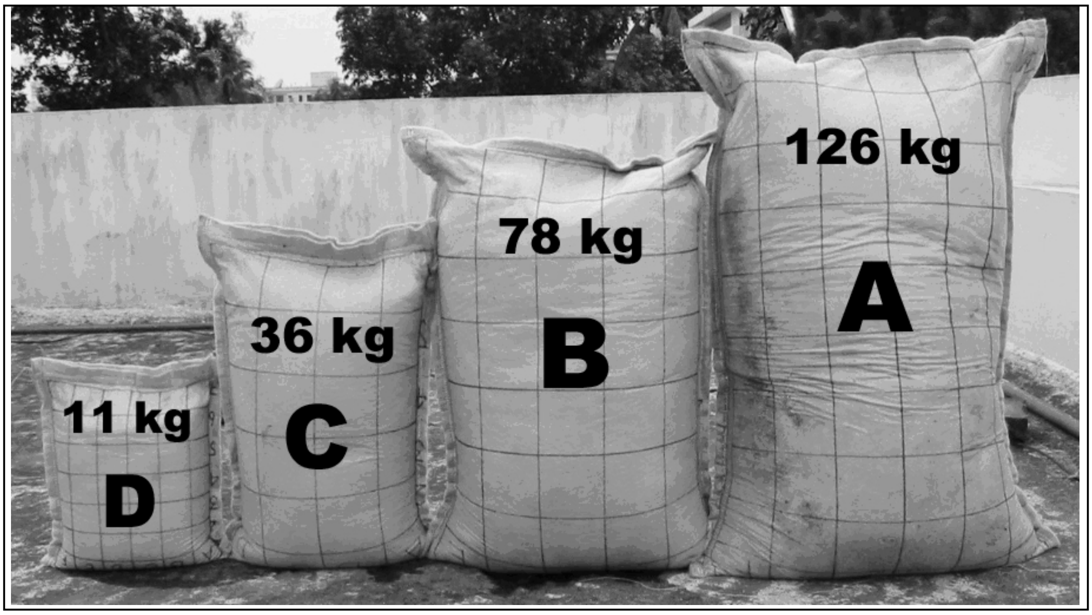

FIGURE 3
GEOBAGS. THE GRID ON THE THREE LARGEST BAGS IS 10 CM BY 10 CM, AND 5 CM BY 5 CM ON THE SMALLEST. THE 126-KG BAG IS APPROXIMATELY ONE METER HIGH.

In the feasibility assessment [3] a gradation of geobags was proposed based on that had been recommended for quarry rock [5] in the USA. The proposed sizes were later modified after field experience in 2002 [4]. The adopted masses of the bags became 11, 36, 78, and 126 kg when filled with dry sand (Fig. 3). All sizes were combined into mix each comprising 25 percent of the total mass. The density of fill sand was taken as 1500 kg/m^3.

d. Modified Designs Implemented since 2004

The first major adaptation based on field experience was to eliminate the two smallest sizes from any more consideration (Tab. I). Now, either one of the larger sizes is judged adequate. This finding was later reconfirmed by hydraulic model tests [6]. For stability against currents, the larger bags are better. As yet, there is no evidence that sand-filled geobags for revetment protection in Bangladesh should be heavier than 126 kg.

A bag filled to 80% of capacity (flatter shape) covers 80% of its unfilled area (length x width), whereas when filled to 100 % (rounded shape) it covers only 75 % of its unfilled area. Based on observations, the latest specifications call for 100% filling with dredged sand. Underwater consolidation reduces the volume to approximately 85 %. There is discussion about the shape still. At this time, there is no compelling reason to change the empty-bag shape.

TABLE 1.
MASS AND SIZE OF EMPTY GEOBAGS

Designation Type	Dry mass (kg)	Length (m)	Width (m)	Length/ Width
A	126	1.03	0.70	1.47
B	78	0.83	0.60	1.38
C	36	0.68	0.45	1.51
D	11	0.40	0.20	1.33

The original feasibility specifications called for non-plastic, non-saline sand free from silt, clay, roots, and other organic materials. The minimum grain size was 0.074 mm, meaning no silt. Experience has indicated that such sand does not leak from the geobags. Moreover, no damage to properly seamed geobags has been experienced when bags are dropped from the water surface.

Diving investigations on the first implemented works indicated that geobags launch down the slope and protect the bank from further erosion. The launching, however, does not result in a multiple layer coverage as assumed during the feasibility study but mostly in a one-layer thick protection. Consequently, the implementation concept was modified to arrive at a stable multiple layer coverage.

Life forms use the geobags as substrate on which to live and grow. Some small tubes built from mica flakes and inhabited by worms about 1 cm long are attached to the surface of geobags. At some places, small snails are attached to the bags; at others, there are fungi on the bag surface.

When the opportunity arises, a 126-kg geobag will be weighed field dry, and then submerged into water. The weight will be monitored until such time as it becomes constant. This will give an indication of how fast the air is expelled. The final weight is the submerged weight of the bag and its sand.

Geobags are manufactured from polypropylene or polyester textile fabric, which is non-woven and needle-punched and not solely thermally bonded. The textile has a density of about 400 g/m^2 and a tensile strength of more than 20 kN/m. It is UV stabilized to ensure retention of at least 70% of its original tensile strength before exposure. The porosity (ratio of the volume of voids to the total volume of fabric) of the geotextile is required to be at least 80%. After observing the unraveling of certain used geotextile materials, abrasion tests have been specified to assure the long-term stability (Fig. 4). There are tests specified for other properties of the geobag material, the bag, and its seams.

FIGURE 4
DIFFERENT TYPES OF GEOBAGS PLACED AS TEMPORARY WAVE PROTECTION. NOTE THE ABRASION OF THE BAG SURFACE OF THE BAG ON TOP

KEY ELEMENTS OF GEOBAG REVETMENTS AT THE PIRDP

a. General Considerations

In the geobags revetment, the geobags form a thin layer over the natural (unprepared) bank slope. No filter is required. The design calls for placing geobags only below low-water level. Above low water, concrete blocks or other hard material are used to provide the additional stability to resist wave attack and to guard against vandalism. Waves produce a significant pounding action on the bags [7] and have moved heavy geobags. When left unchecked, waves cut a vertical notch in the more cohesive top bank. Also, geobags above water have been sliced, drained of sand and the fabric taken was to serve such functions as drapery for doors.

On the revetment, the geobags are subjected to fluctuating hydrodynamic forces of pressure and shear caused by the water flowing over them. Gravity is the main stabilizing force acting to hold the geobags in place against hydrodynamic forces - provided that the bank is not too steep, in which case gravity can become a de-stabilizing force.

Beneath the thin layer of geobags is the natural bank material consisting of sand, silt, or clay, which also must be stable in a geotechnical sense.

Riverbed scour at the toe of the bank is a most important factor affecting bank slope stability. The river bed at the Project consists of fine and very fine sand, with median diameters of 0.1 to 0.3 mm. Almost any river flow can disturb this material, and floods move great masses of bed material eroded from the bank and picked up from the bed and sandbars. A local rate of scour deepening of 5 m/day has been measured at the lead spur for protection works in the Jamuna River at Sirajganj [8].

In hydrodynamic stability assessment, it is assumed that the bank slope behind the geobag skin is stable and that the bags do not slide on the bank material, only on each other. The hydrodynamic forces tend to move the bag downstream. The gravity force has an against-slope component tending to keep the bag in place and a down-slope component tending to move it down the slope. Adjacent bags can affect stability depending on their own stability and orientation and on the points or areas of contact.

b. Physical Hydrulic Model Tests

The hydrodynamic behavior of geobags was investigated by hydraulic model testing at a geometric scale of 20 to 1 (prototype to model) in the laboratory of nhc in Vancouver, Canada [6]. Model geobags, consisting of permeable cloth fabric filled with fine sand, were placed on banks formed in crushed walnut-shells at slopes of 1V:1.5H and 1V:2H. They were displaced at the incipient motion velocities shown in Table 2. The tabulated bag masses are sand-filled dry scaled-up prototype values, and the "bank" velocities represent scaled-up depth-averaged values at a point one-third of the slope length inshore from the initial toe of the slope.

TABLE 2.
INCIPIENT MOTION VELOCITIES (PROTOTYPE VALUES)

Mass of Geobag (kg)	Bank Velocity (m/s)
Slope 1V:1.5H	
126	2.6
90	2.4
38	1.7
Slope 1V:2H	
126	2.9

Incipient motion velocities for angular rock (22 kg), rounded rock (50kg) and concrete blocks (65 kg) were determined in the model as well. Incipient motion velocities were practically the same for all three *and* for the 126-kg geobags.

The model information was analyzed in the context of the U.S. Army Corps of Engineers' design equation [5,9] for rock riprap used as bank protection:

$$\frac{D_{30}}{Y} = S_f C_S C_V C_T \left(\frac{V^2}{K_1 g Y} \quad \frac{\gamma}{\gamma_s - \gamma} \right)^{1.25} \qquad (1)$$

where

V = local vertically-averaged velocity
S_f = safety factor, minimum recommended value for riprap design = 1.1
C_s = 0.30 for angular rock and 0.36 for rounded
C_V = coefficient for vertical velocity distribution, range 1.0 to 1.28 for straight channels to abrupt bends
C_T = coefficient for riprap layer thickness, 1.0 or less with increasing thickness
K_1 = side slope correction factor
D_{30} = size of stone for which 30 % by weight is finer
Y = depth of flow
γ = specific weight of water
γ_s = specific weight of stone

Key values recommended for the side slope correction factor K_1 are as follows (Table 3):

TABLE 3.
CORRECTION FACTORS FOR SIDE SLOPES

Slope	Slope angle (degrees)	Correction Factor K_1
1V:1.5H	33.5	0.71
1V:2.0H	26.5	0.88
1V:3.0H	18.0	1.00
Flatter than 1V:3.0 H	-	1.00

From the experimental results it was determined that a value of 0.77 should be used for the shape factor C_s for the two largest model geobags bags on 1V:2H and 1V:1.5H slopes. The diameter of a geobag was taken as the cube root of the volume.

It has been reported [10] that when the flow velocity exceeds 1.5 m/s or so, sand can move inside a bag from the upstream to the downstream side. In special cases a bag could roll because of this movement. Such sand movement could not occur in the model geobags, and has not been observed to date in the field. Velocities at or adjacent to the bags on the revetment are generally not this high.

Model geobags slide over each other on bank sloes of approximate 52 degrees. Prototype bags are just slightly less stable, sliding over each other on slopes of 47 degrees

Model 90-kg geobags were dropped into a 10-m depth of water flowing at 1.7 and 3.3 m/s (scaled-up prototype values). It was difficult to achieve complete coverage even when the bank was visible and bags were dropped to cover an observed bare spot. Bags tended to cluster in random piles surrounded by bare patches. Mixtures of bags achieved even more precarious coverage.

c. Geotechnical Studies

Geotechnical aspects discussed in this report include movements in the riverbank soil and on the interface between geobags and bank material. This includes geobags sliding on sand, and bags and sand bonded so that bags plus underlying sand slide on sand.

Before the installation of geobag protection, eroding banks at the Project were characterized by erosion of sand from the bank slope and river bed by currents, followed by geotechnical failure of the more cohesive upper layer, extending from the top of the bank down to low-water. Wave erosion was also an important factor.

In the feasibility study [2,3], it was recommended that the upper slope of the bank be dressed to 1V:2H before placing the geotextile filter and concrete blocks. The launching heap would consist of a graded mixture of geobags dumped below low water. The width of the heap, normal to the bank, would be based on the design scour depth. The riverward slope of the heap was set at 1V:1.25H (approximately 39 degrees to the horizontal). The angle of repose for model geobags is 52 degrees, but the bags could be heaped at a steeper slope by piling them. The launched slope was considered stable.

Model tests at BUET [3] indicated that if a slope failure occurs for one reason or another - for example, the loose state of the soil - the geobags have no chance to launch. Rather, they fail as a whole, the heap sliding down the slope as a unit.

Considerable geotechnical investigation has been done for the Project, including drilling and logging boreholes, and estimating soil strength properties. At the Project, the slopes are generally stable. For inclinations steeper than 1V:2H (Fig. 5), slope stability where it exists results from"hidden stabilizing influences," that is, geotechnical factors that are not taken into consideration in common practice. The steep parts of the natural slopes are considered to be at the "ultimate limit of stability."

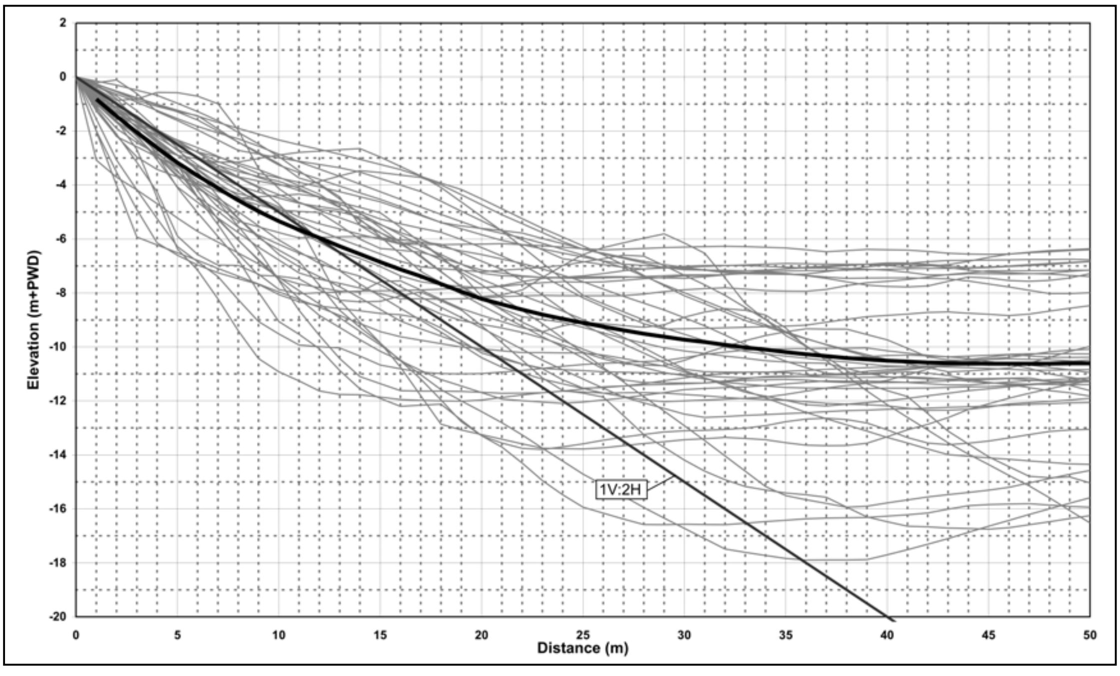

FIGURE 5
BANK PROFILES TAKEN AT THE ERODING SECTION IN APRIL 2004 WHEN THE WATER LEVEL WAS APPROXIMATELY +5.0 M PWD.

There is an upper layer, 5 to 6 m thick, of floodplain soil consisting of clay and clay-silt with low plasticity. The clay layer reaches down from floodplain level to approximately low-water level. Below this upper clay layer, the bank consists of fine-grained and poorly graded sand of medium compactness. The specific weight of the sand grains is taken as 26.5 kN/m^3. The effective shear strength of the clay allows for vertical faces up to 4 to 5 m high.

Sand dominates the overall stability. It can fail below the clay, and then the clay collapses afterwards. Sand usually fails more or less on a flat plane, the movement being in the form of a wedge translation. Slip circle failures are uncommon.

For the flatter slopes of 1V:2H to 1V:2.5 H, the angle of internal friction is 28 to 30 degrees. For slopes of 1V:1.5H and steeper, the angle of internal friction is 32 to 35 degrees.

There are three geotechnical ways the slope can fail. They are: geo-mechanical; flow slide of sand; and liquefaction due to dredging or earthquakes. Scour (erosion of bed and lower bank material by flowing water) is an important factor triggering the slope failure process. Scour is considered a hydrodynamic issue.

The slopes are prevented from such failures by protecting the toe and lower bank erosion that would steepen the slope, preventing rapid changes in soil stress levels at the toe of the bank, and stabilizing the top bankline.

d. The Adaptive Approach

In the feasibility study it was conceived that a heap of geobags of different sizes placed along the bank just below low water would launch when undercut by erosion and cover the eroding area with a 0.9 m thick layer of protection. Divers' observations clearly showed that this did not happen. The coverage was either by single bags or sometimes lumpy with bare patches. The smallest bags disappeared. Clearly adaptations were needed.

For predominantly construction purposes, single-size geobags are favorable so only 126 kg bags will be used for future work in Jamuna River. The smaller size of 78 kg is proposed for smaller rivers. If there is to be a mix, it will be with the 78- and 126-kg bags.

The protective system was to remain geobag revetment protection below low water level and concrete blocks or interconnected systems such as grout-filled mattresses above low water.

A multi-step implementation system combining a fast response to erosion threat and an optimized use of bags has been developed and implemented that has provided satisfactory protection.

Immediate Protection: Imminent river erosion requires a fast response. This is provided through mass dumping of bags along the eroding bank, allowing the bags to launch down the slope (Fig. 6). The result is a commonly one-bag thick cover layer, which substantially reduces erosion rates but is not stable in the long run. During this initial stage only temporary wave protection above low water level, consisting of geobags, can be provided.

First level protection: A three-bag layer is placed over the launched bags making, on the average, a four-layer thickness on the slope after completion of this first level protection (Fig. 7). In addition, a thin and wide falling apron for the expected future scour is placed at the toe of this protection. Lately, 12 to 15 m wide falling aprons are built consisting of three layers of bags. This falling apron can cover up to 15 m scour depth.

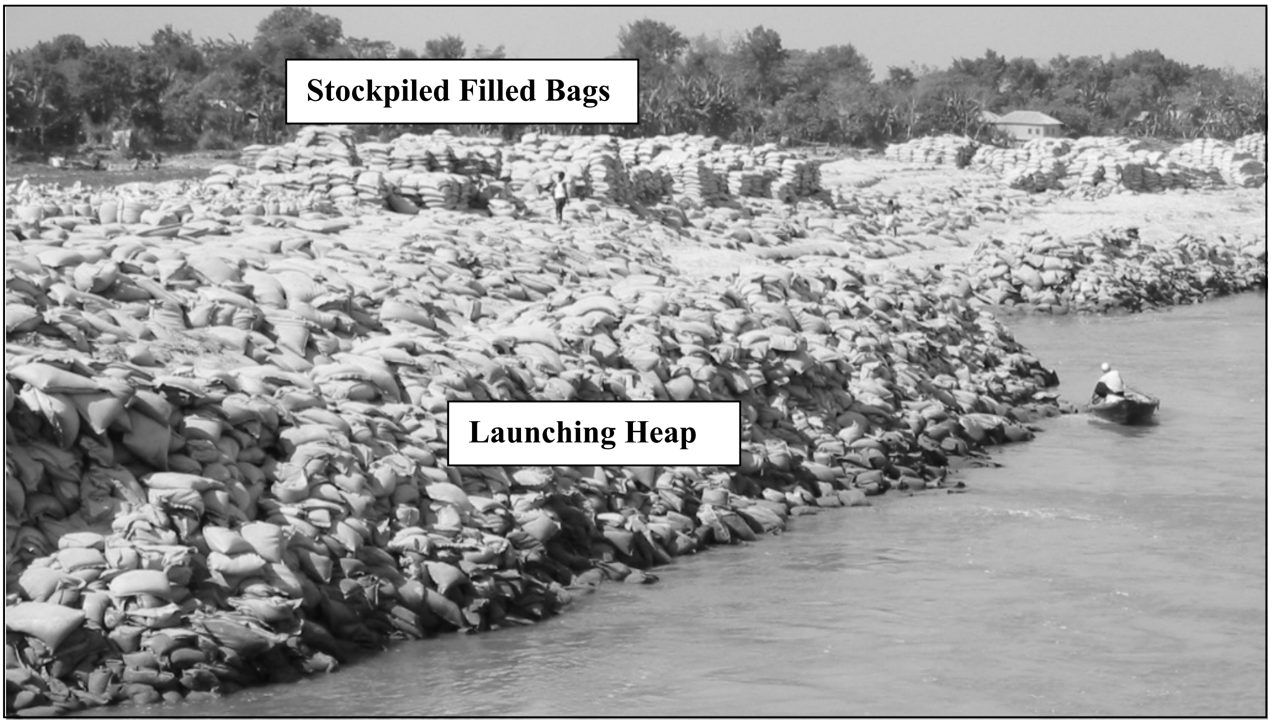

FIGURE 6
IMMEDIATE PROTECTION IMPLEMENTED AT THE PIRDP IN 2002.

FIGURE 7
1ST LEVEL PROTECTION DUMPED FROM POSITIONED BARGES

Adaptation: The river response to protection commonly results in toe scour along revetments. For this purpose falling aprons are placed along the toe. These falling aprons may have to be upgraded to first level protection after their deployment. In addition to depth changes, the erosion can shift in upstream or downstream direction. In these cases, immediate and first level protection will be repeated for areas under new attack.

Second level protection: The river reacts to the bank protection during the initial years and there are changes to the overall morphology. Settlements and adjustments of the unprepared uneven bank will occur. Scour might reach deeper levels and the falling apron at the toe starts deploying. The second level protection is designed to improve the protective layer of first level protection and subsequent adaptation works and to arrive at a more uniform surface. It is planned to place 1.5 layers of bags after reaching deepest scour depths.

Maintenance: Regular maintenance is a long-term operation during the lifetime of the protective system. The normal maintenance is expected to start about 5 to 10 years after implementation and after completion of second level protection to deeper scour levels.

Phased Construction and Monitoring: To obtain sustainable bank protection several phases of construction in the same area are required. A period of monitoring and adaptation follows the initial immediate and first-level protection construction. The phased implementation concept requires plenty of resources for monitoring and supervision.

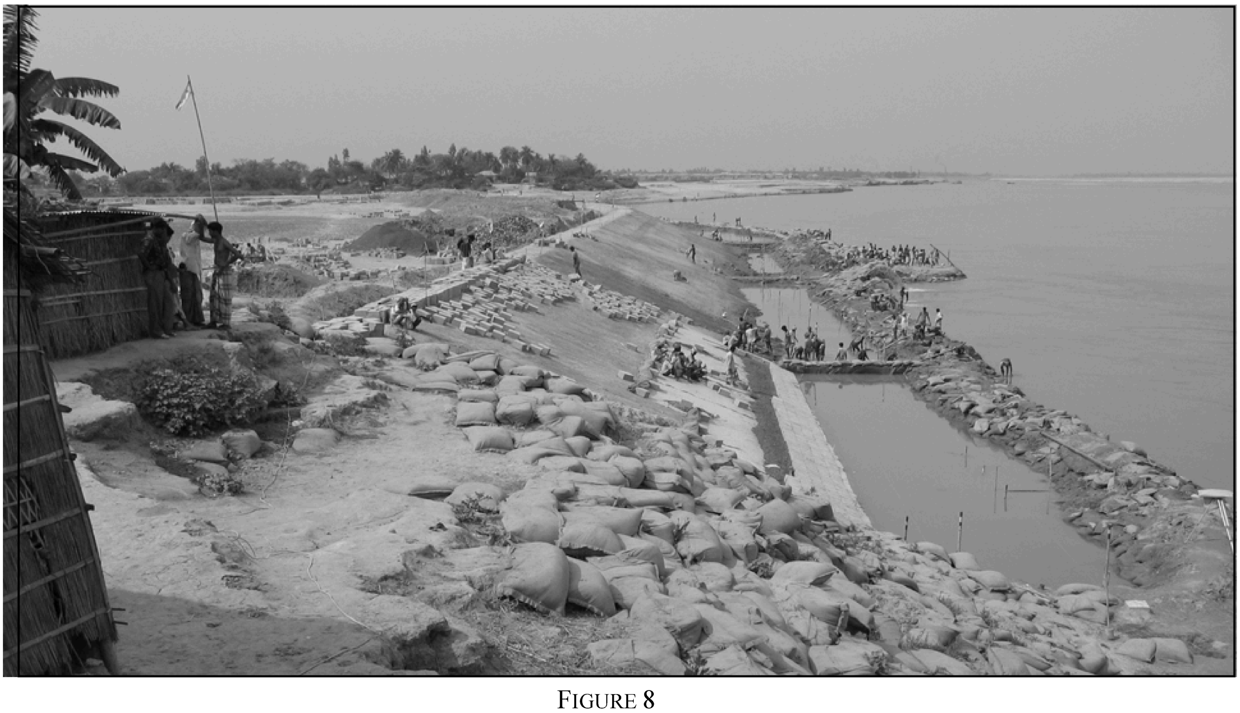

FIGURE 8
CONSTRUCTION OF PERMANENT WAVE PROTECTION ABOVE LOW WATER LEVEL DURING THE ADAPTATION PHASE

SUMMARY

The hastily designed and constructed emergency geobag revetment prevented the PIRDP from becoming a disastrous failure. It was a success! To date, more than five million geobags have been placed here and at the Padma-Upper Meghna confluence. Nearly all phases of the initial concept have been modified based on field (most importantly, diving inspections) and laboratory experience. This adaptation method is used to adjust the works to suit conditions that cannot be predicted and to make improvement to any aspect of the works deemed deficient, whether it is in design, construction, management, scheduling, or other issue. The revetment derived at is the most cost effective solution at estimated cost of around USD 2 M per kilometer on average.

ACKNOWLEDGMENT

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